Investigation of Digitally Controlled Oscillator Operability Problems

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In order to provide adequate levels of flight project support, the elimination of procedural errors by Deep Space Network personnel is an important consideration. This article describes an investigation designed to identify and correct procedural errors involving digitally controlled oscillator operations.

I. Introduction

The digitally controlled oscillator (DCO) is a microprocessor-based exciter frequency controller that serves as the prime uplink control unit on the 64-meter and 34-meter subnets. The DCO is controlled by a Deep Space Station (DSS) operator through either the Metric Data Assembly (MDA) in automatic mode, or a dedicated terminal in manual mode.

The DCO has been the source of numerous support problems since its implementation in July 1980. These problems can be categorized as either hardware, software, or operational problems. The identification and correction of operational problems is the responsibility of the Operations Control Group, Control Center Operations Section. These problems are documented, through the DSN Discrepancy Reporting System, as procedural discrepancy reports (DR's). The large number of procedural DR's involving the DCO indicate that the DCO suffers from poor operability. The term "operability" refers to the relative ease or difficulty encountered by an operator in attempting to operate a system correctly.

The methods used for identifying and correcting hardware and software problems are fundamentally different from the methods used to identify and correct operability problems. Hardware and software problems can be dealt with through the use of step-by-step troubleshooting procedures, which lead directly to identification of a bad component or an incorrect line of code. Operability problems, however, are less tangible in nature because they originate at the interface between the DCO and its human operator. This person/machine interface is therefore the area that must be investigated when attempting to identify and correct operability problems. The methods used to investigate operability of a system are provided by the fields of behavioral science and human engineering.

II. Investigation

A. Investigative Strategy

Operability in a complex system is the result of the interaction of many variables. These variables provided a framework for analysis of the data. The variables deemed most relevant to DCO operability were:

(1) The person/machine interface.

(a) Physical operations environment.

(b) Complexity and comprehension of input and output.

(c) Time constraints.

(d) Personality factors.

(2) Information transfer procedures.

(a) Information transfer medium (voice, hard copy, CRT).

(b) Memorization requirements.

(3) Procedural documentation.

(a) Metric Data Assembly Software Operator's Manual (MDA-SOM).

(b) Other documentation (Synthesizer Controller Technical Manual, DCO Procedures, TWX's).

B. Data

The data for this investigation were extracted from 45 procedural DR's involving the DCO over a period of 14 months from August 1980 to September 1981. Additional information regarding DCO operability was provided by interviews with station operators, reviews of DCO procedural documentation, and observations of DCO operations at DSS 14. Analysis of the data attempted to answer three major questions:

(1) Were procedural errors distributed evenly throughout all DCO-equipped stations?

(2) Did the procedural error rate for DCO operations remain steady over time, or did it fluctuate in response to external events?

(3) What types of errors occurred most often?

C. Results

No evidence was found to indicate that any DCO-equipped station was more prone to operability problems than any other DCO-equipped station. Within the 14-month period, the mean number of procedural DR's per station was 6.4, with a standard deviation of 2.87.

Several interesting phenomena were evident when the DR's were examined over time (see Fig. 1). The gradually decreasing error rate seen between August 1980 and February 1981 indicated that learning and familiarity over time aided station operators in reducing the procedural error rate to near zero. This gradually decreasing error rate is what one would expect to see following introduction of a new system. The dramatic increase in procedural errors seen in March, April, and May of 1981 was due to the implementation of new MDA software, which the station operators also needed time to become accustomed to.

The procedural DR's were also categorized by type of error. The following list indicates the most prevalent types of errors:

(1) Incorrect command.

(2) Incorrect command syntax.

(3) Commands entered in wrong sequence.

(4) Wrong predicts selected.

(5) Incorrect frequency entered.

The last category, incorrect frequency entered, accounted for more than 25% of all procedural errors involving the DCO. No other problem category accounted for more than 10% of the total errors.

Interviews with station operators and observations of DCO operations pointed out several contributory factors to poor operability. Many errors occurred during high-activity periods at the station, especially during tune-in shortly after acquiring the downlink. At least two procedural errors also occurred during shift changes. Another factor is the time constraint associated with several DCO commands, which must be entered at least 4 minutes prior to the start of tuning.

A review of procedural documentation indicated that complete procedures did not exist for all possible modes of operation and that the MDA-SOM did not contain adequate uplink tuning procedures. Station operators also noted that procedural documentation was often not timely and not formatted so as to be easily usable.

Most of the problems regarding procedural documentation have recently been alleviated, as described below.

D. Discussion

The investigation results indicated that entering frequencies was the most error-prone aspect of DCO operations. These frequencies are large numbers, typically containing from 9 to 14 digits. The types of errors occurring most often involve transposition of digits or substitution of incorrect digits for correct digits. These errors are due to the memorization requirements of information transfer procedures, especially when information is being transferred via voice net. The capacity of human short-term memory is generally limited to about 7 discrete items of information. These items can be kept active indefinitely in memory by internal rehearsal; however, the potential for incorrect memorization increases as the number of items to be remembered increases. Multidigit numbers, therefore, become progressively harder to remember correctly as the number of digits is increased.

Another important feature of human memory is that even visually presented information is stored in acoustic form. For example, if a person is given a list of letters of the alphabet to memorize, and makes an error in recalling the letter "F", he is much more likely to report it as an "X" than an "E". Although "F" and "E" share common visual features, "F" and "X" share a common initial sound. This phenomenon is known as acoustic confusion. When memorizing large numbers, therefore, 2's are confused with 3's, 4's with 5's, and 6's with 7's.

Based on these findings, recommendations were made in June 1981 to carefully double-check frequencies, especially when they are passed to the station operator via voice net. Since this recommendation was implemented, only one procedural error involving entering a wrong frequency into the DCO has occurred.

Another possible source of error in DCO operations is the nonstandardization of delimiters. For example, certain MDA commands for entering the date and time use spaces as delimiters, while equivalent DCO commands use colons as delimiters. This lack of standardization was the cause of at least one procedural error.

Procedural documentation was often mentioned by station operators as contributing to poor operability. Procedural documentation must accommodate both heuristic thinkers, who reason in global or system terms, and analytic thinkers, who reason in linear terms.

In May 1981 a special team was formed to rewrite the then-current DCO operations procedures. These new procedures were implemented in early June and were largely responsible for the reduction in procedural errors since then. As of this writing, only one procedural DR involving the DCO has been written in October.

Bibliography

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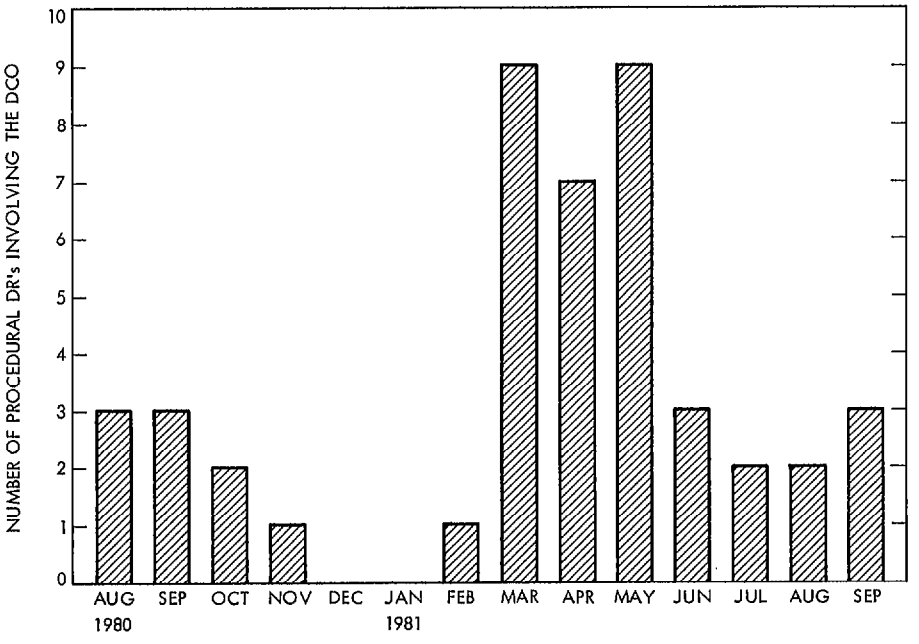

Fig. 1. Procedural DR's per month since DCO installation